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(54) **APPARATUS FOR RANDOM ACCESS MEMORY ARRAY SELF-REPAIR**

(75) Inventors: **Louise A. Koss**, Ft. Collins, CO (US);
Mary Louis Nash, Fort Collins, CO (US);
Dale Beucler, Ft Collins, CO (US)

(73) Assignee: **Agilent Technologies, Inc.**, Palo Alto, CA (US)

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|-----------------|---|---------|-------------------|-----------|
| 5,577,050 A | * | 11/1996 | Bair et al. | 714/710 |
| 5,742,556 A | * | 4/1998 | Tavrow et al. | 365/225.7 |
| 5,764,577 A | * | 6/1998 | Johnston et al. | 365/200 |
| 5,764,878 A | * | 6/1998 | Kablanian et al. | 714/7 |
| 6,021,512 A | * | 2/2000 | Lattimore et al. | 714/710 |
| 6,065,134 A | * | 5/2000 | Bair et al. | 714/7 |
| 6,067,262 A | * | 5/2000 | Irrinki et al. | 365/201 |
| 6,076,176 A | * | 6/2000 | Priore et al. | 714/710 |
| 6,185,709 B1 | * | 2/2001 | Dreibelbis et al. | 714/726 |
| 6,366,508 B1 | * | 4/2002 | Agrawal et al. | 365/200 |
| 6,671,822 B1 | * | 12/2003 | Asher et al. | 714/8 |
| 6,691,252 B2 | * | 2/2004 | Hughes et al. | 714/30 |
| 6,691,264 B2 | * | 2/2004 | Huang | 714/723 |
| 6,697,290 B2 | * | 2/2004 | Koss et al. | 365/200 |
| 2004/0062095 A1 | * | 4/2004 | Templeton et al. | 365/200 |

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(52) **U.S. Cl.** **365/200**; 365/201; 365/189.02; 365/189.05; 365/189.12; 365/230.02; 365/230.03; 365/230.08

(58) **Field of Search** 365/200, 201, 365/189.02, 189.05, 189.12, 230.02, 230.03, 230.08

(56) **References Cited**

U.S. PATENT DOCUMENTS

5,515,383 A * 5/1996 Katoozi 714/732

OTHER PUBLICATIONS

U.S. Appl. No. 10/008,382, filed Dec. 5, 2001, Louise A. Koss et al.

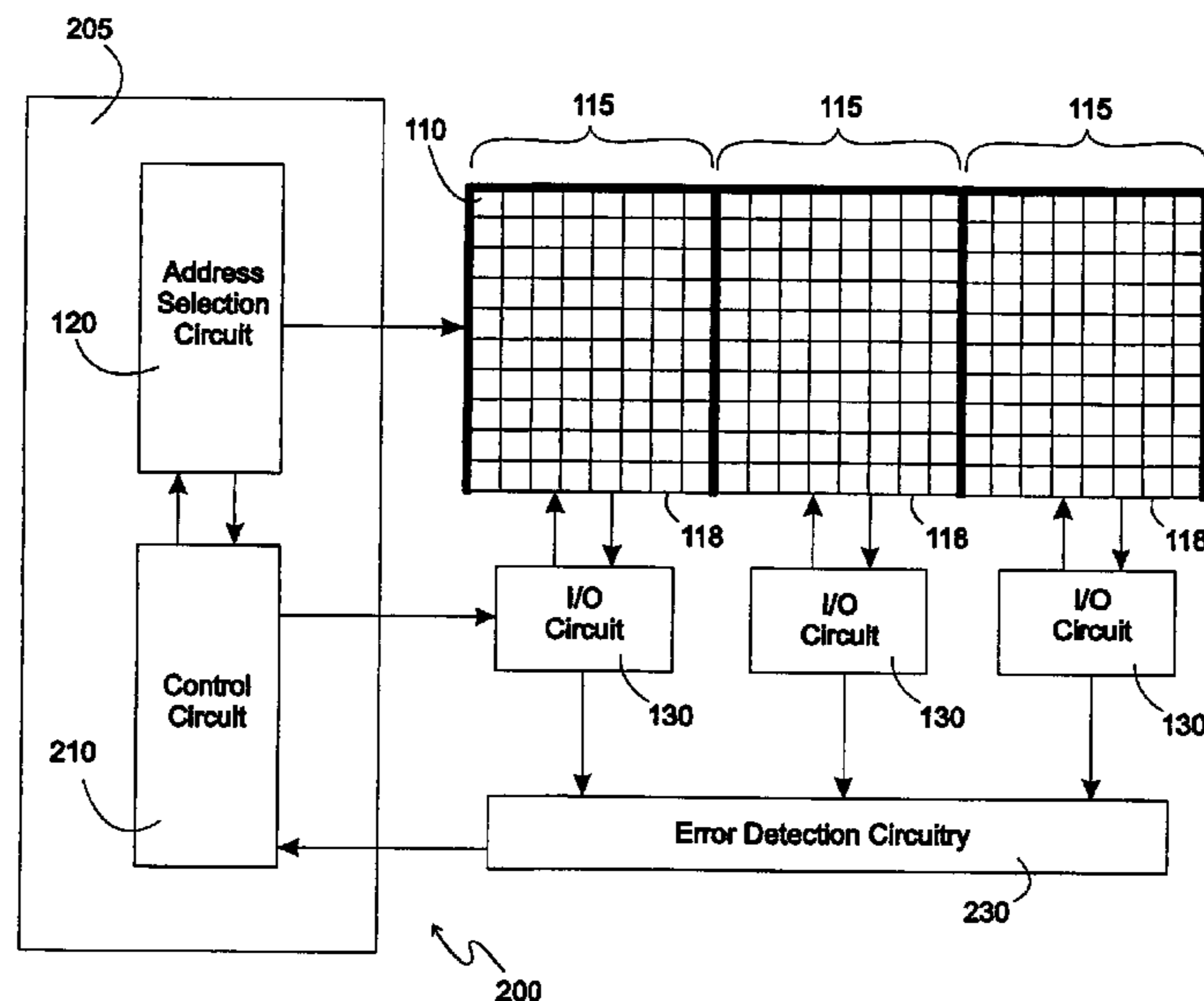
* cited by examiner

Primary Examiner—David Nelms
Assistant Examiner—Ly Duy Pham

(57) **ABSTRACT**

An apparatus for the on-chip, soft repair of random access memory arrays. In representative embodiments, circuitry is disclosed which provides the ability to soft repair defective random access memory arrays. The disclosed techniques for repair of random access memory arrays do not use techniques such as laser repair in the removal of defective parts of the integrated circuit and its replacement with a redundant part. No additional processing steps are involved. The circuitry necessary to repair defects in random access memory arrays is included on-chip in the input/output blocks of the RAM.

15 Claims, 6 Drawing Sheets



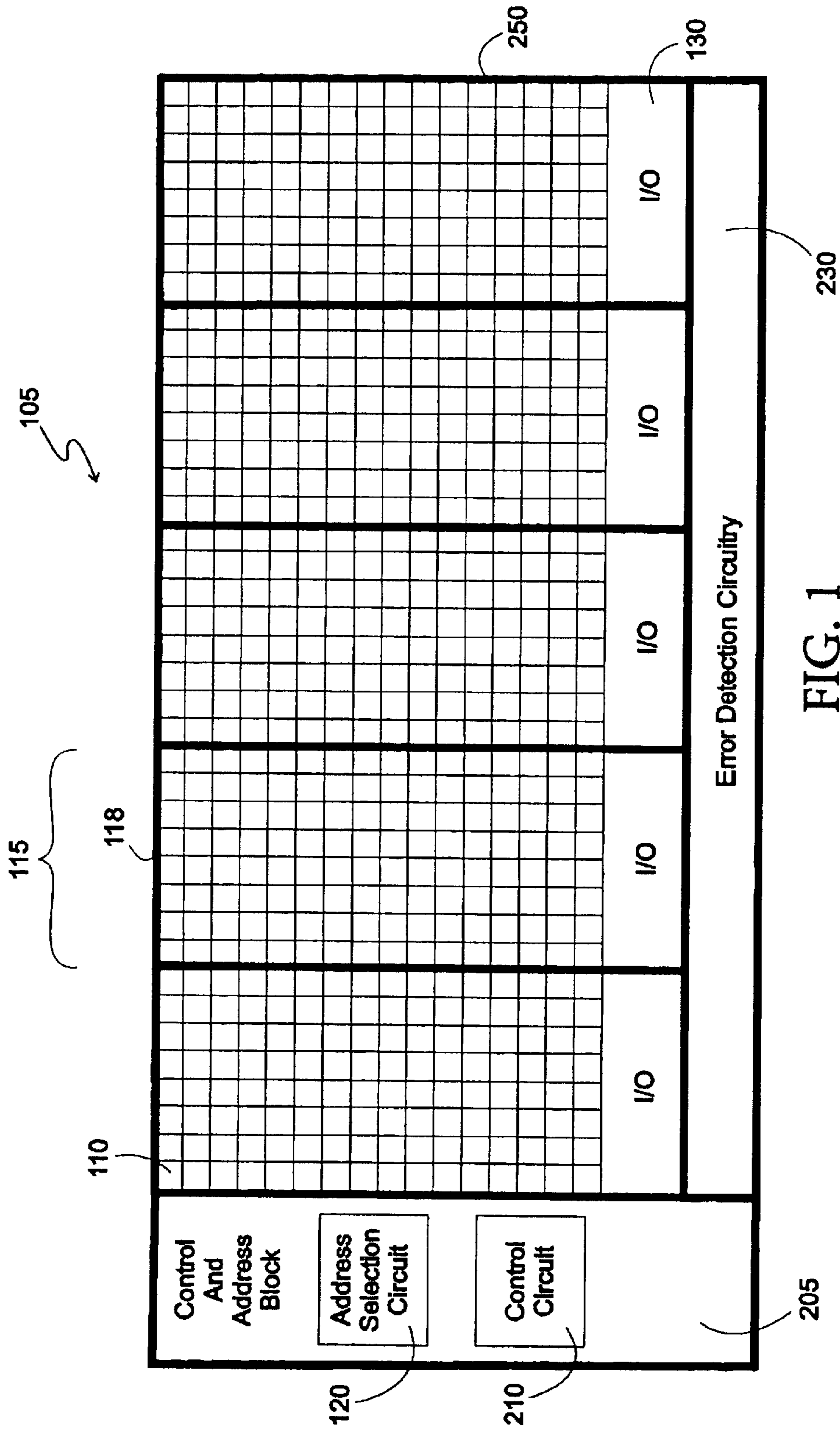


FIG. 1

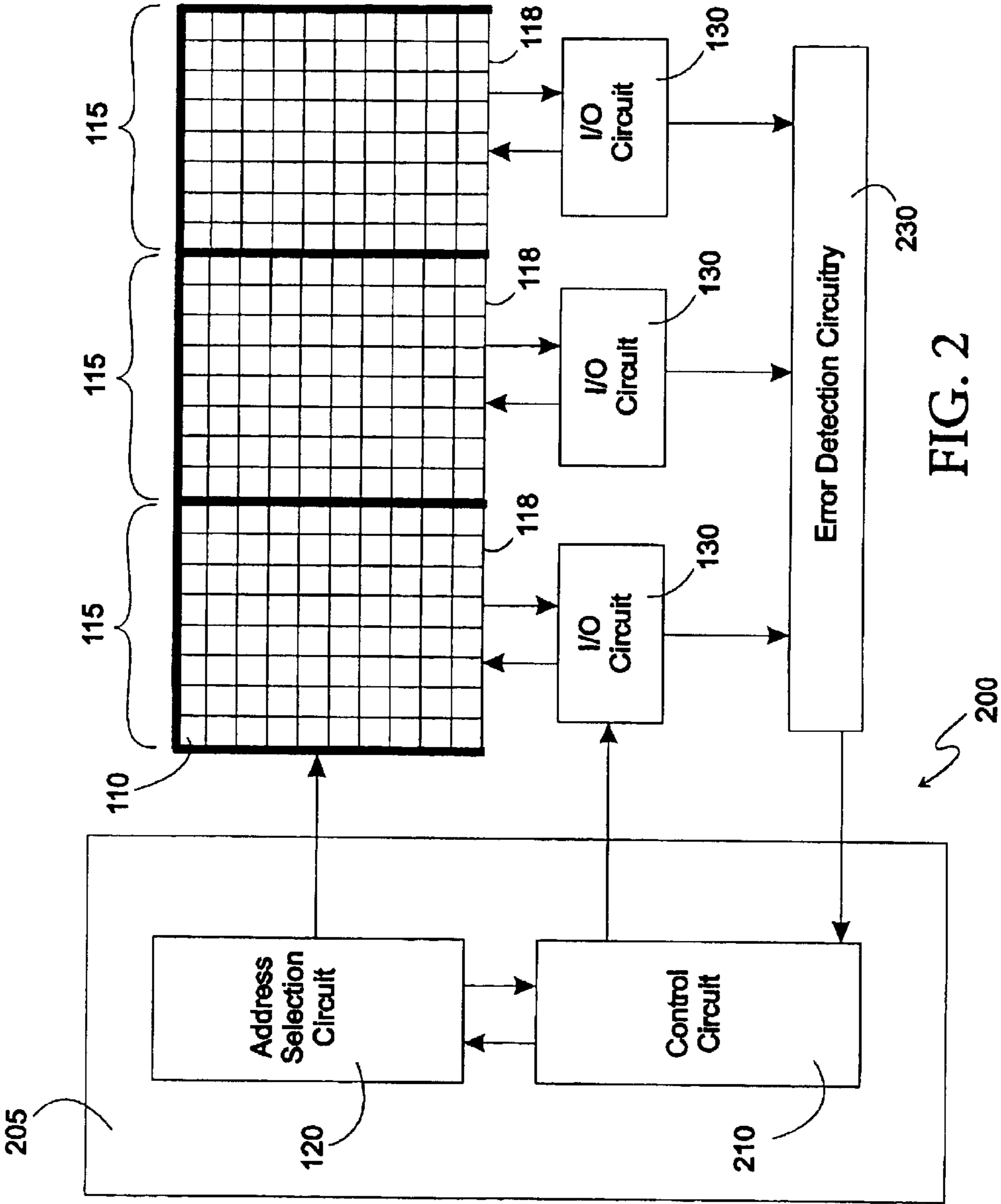


FIG. 2

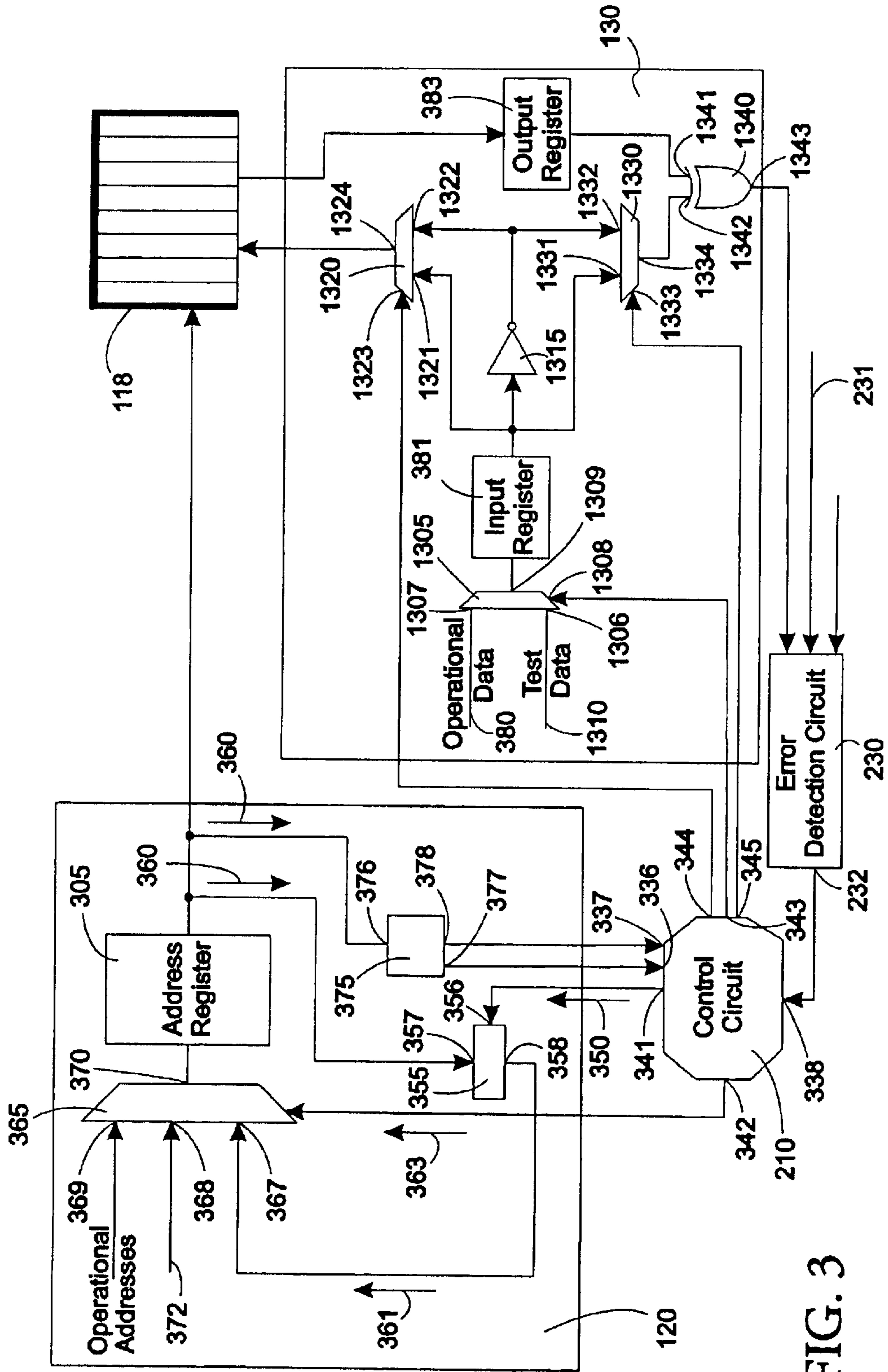


FIG. 3

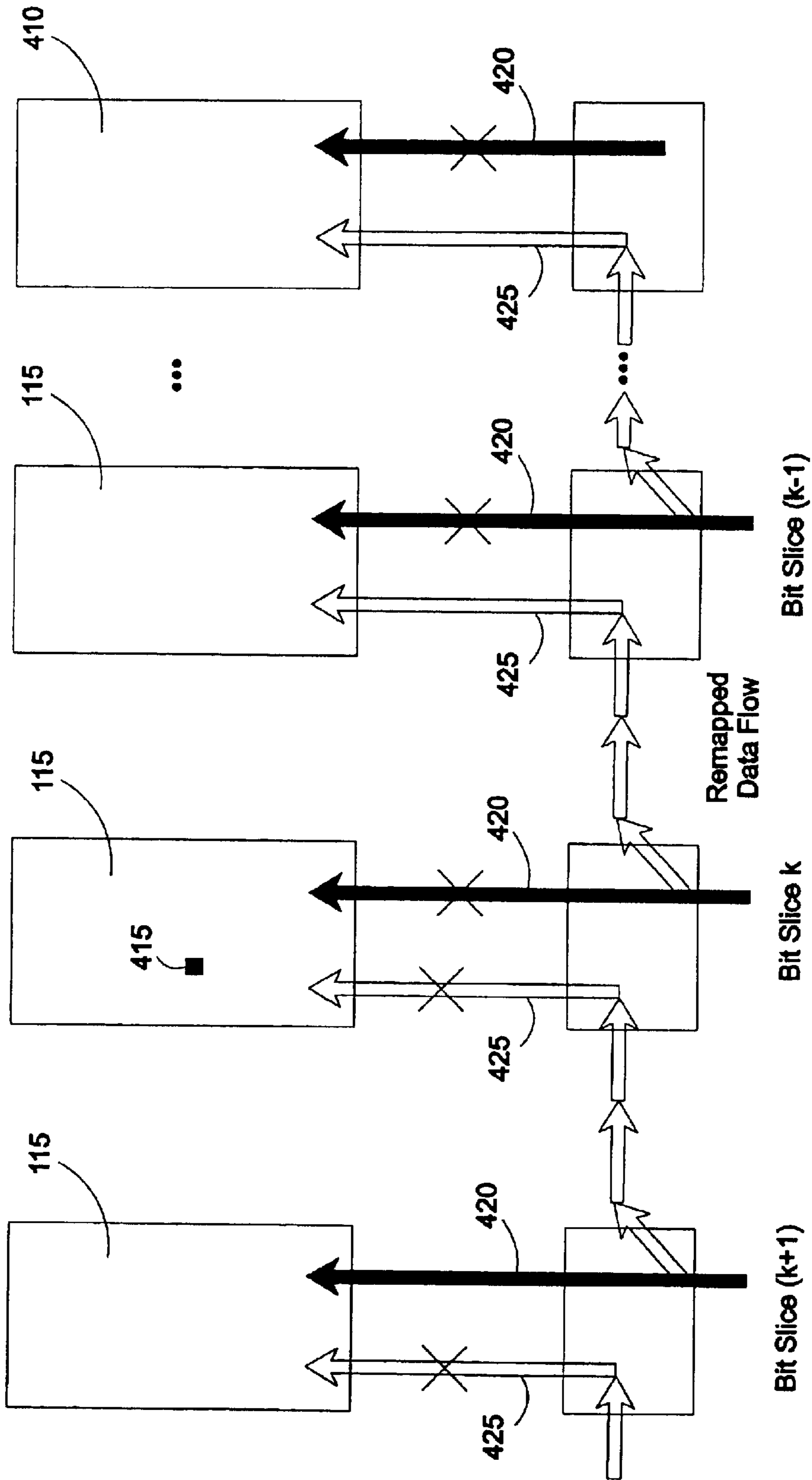


FIG. 4

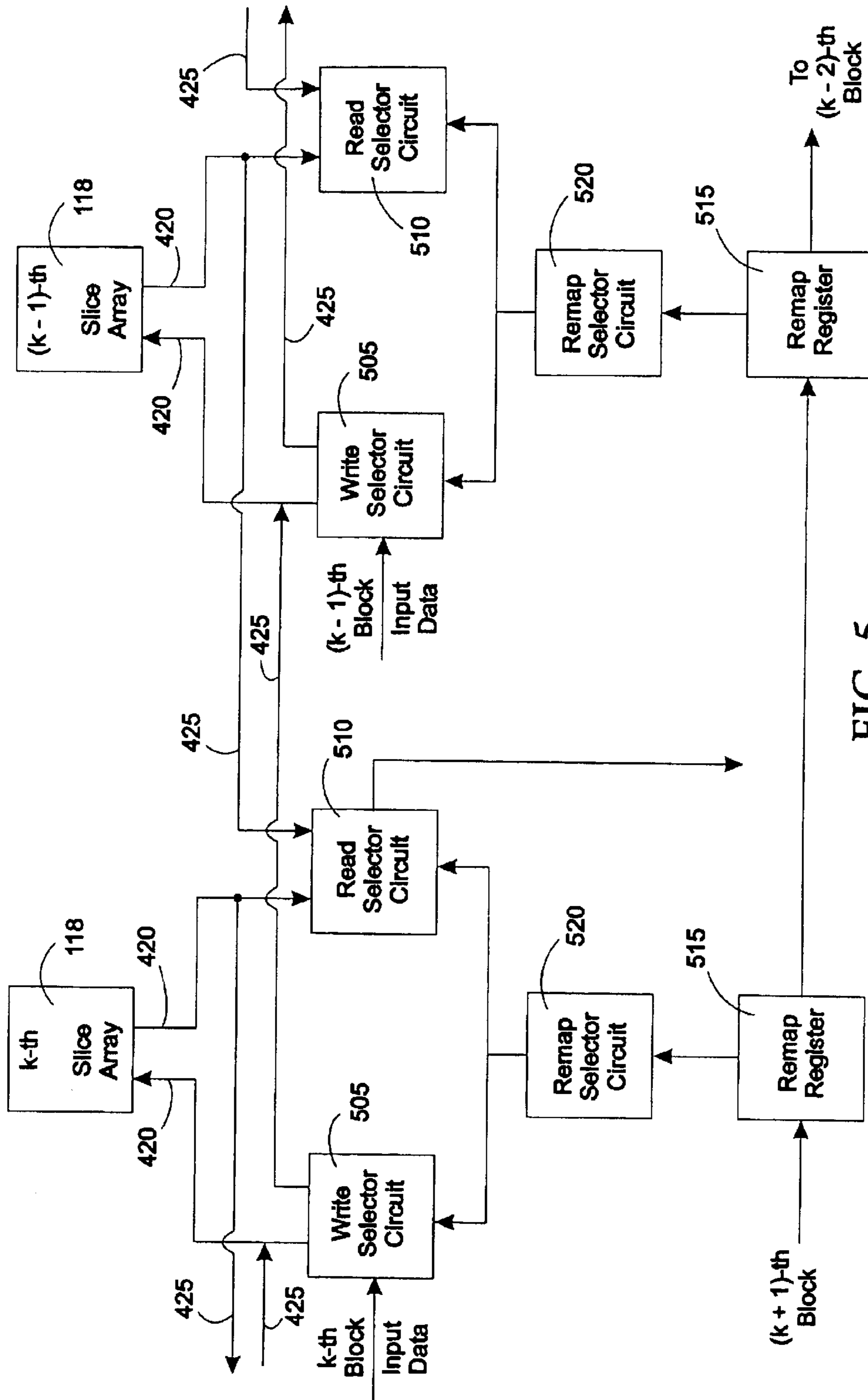
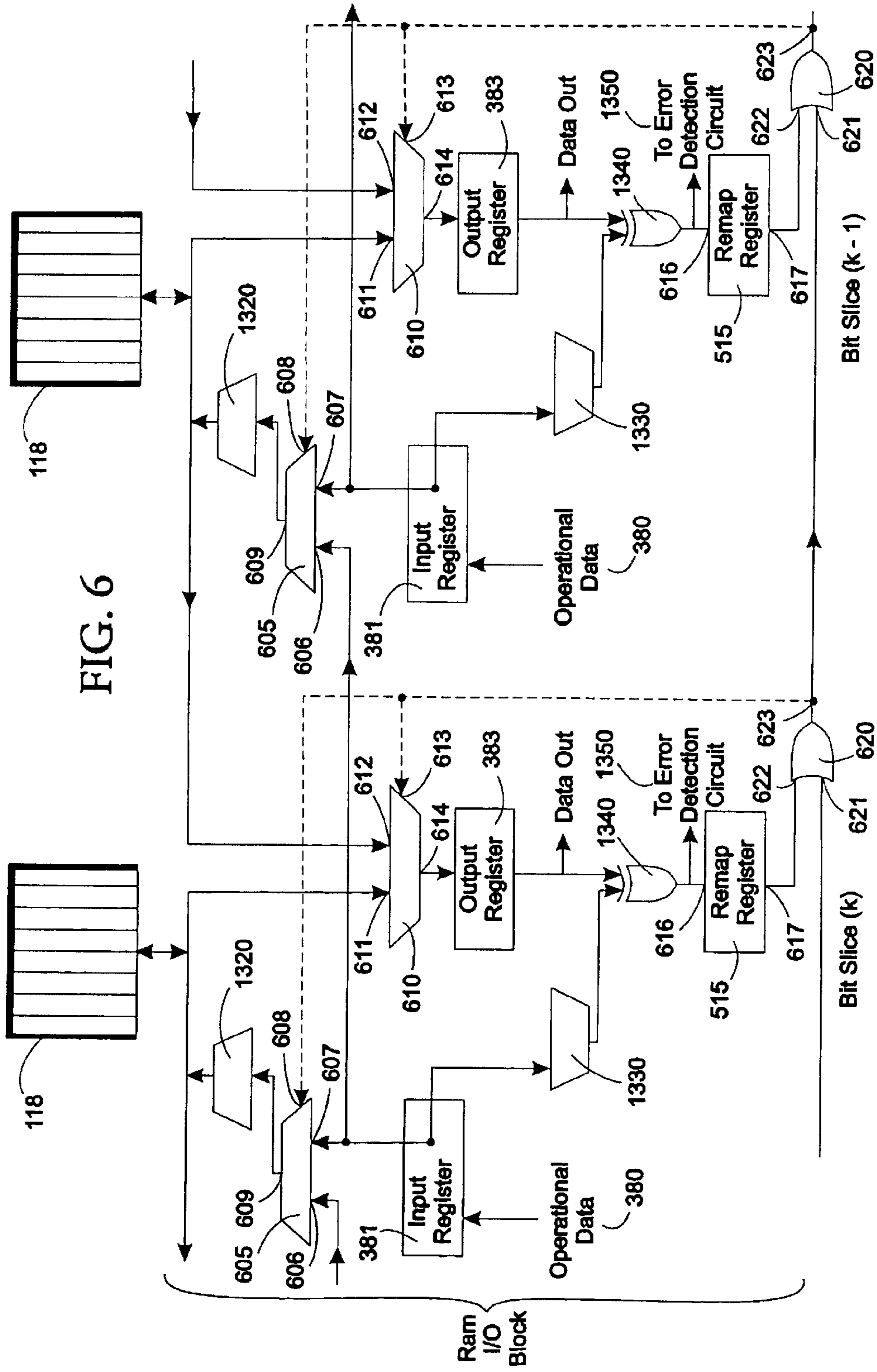


FIG. 5



APPARATUS FOR RANDOM ACCESS MEMORY ARRAY SELF-REPAIR

This is a Continuation of application Ser. No. 10/021, 614, filed on Dec. 12, 2001 now U.S. Pat. No. 6,697,290, the entire disclosure of which is incorporated herein by reference.

FIELD OF THE INVENTION

The present invention relates generally to random access memories (RAM) in integrated circuits and, more particularly, to the test of such circuits and, even more particularly, to their test and repair on-chip.

BACKGROUND OF THE INVENTION

Motivated by the desire for both lower cost and higher performance, integrated circuit (IC) technology has moved throughout its history toward building larger and larger circuits comprising more and more devices. The development of random access memory (RAM) integrated circuits have shared in this movement. In the sense of containing a larger number of memory cells where each cell can store one bit, the larger a RAM becomes, the more difficult and expensive it is to test it. Also, the more expensive the cost of a defect in the circuit, as a single defect can result in the loss of the whole chip.

Not only are RAM's fabricated as stand-alone chips, but they are also built embedded as function blocks in other integrated circuits. Such integrated circuits could be designed and produced as standard chips intended for a variety of applications and as application specific integrated circuits (ASIC's).

With the size and complexity of modern integrated circuits including RAM's, testing has become an important issue. Size and cost constraints limit the area on the integrated circuit available for use as wire bonding pads, flip-chip solder bumps, and the like with the resultant effect of limiting access to the various functioning areas of the chip. So, not all functions of the chip are externally available for direct test. Even if connections to some of these areas were available, the long traces and additional external circuitry necessary to access them would introduce signal delays that could render the results of such testing questionable. Thus of necessity, some testing circuitry is now often included on-chip.

On-chip testing also has its share of difficulties as chip area available for testing is limited, as is accessibility to nodes for testing. Delays introduced by trace lengths also continue to be an issue. In addition unless the chip is designed for mass production, the costs associated with design, manufacturing, and test can be prohibitive.

Additional, redundant circuitry is often included in large integrated circuits. Techniques available, as for example laser fusing, permit the removal of defective parts of the IC and its replacement with the redundant part. This process is cost effective, since on average the added cost of the redundant circuitry is less than the cost associated with the yield loss without the additional circuitry. The addition of redundant circuitry is especially valuable for circuits with repeating structure function blocks, such as RAM and other types of memory. In such circuits a limited number of defective cells can be replaced with the redundant cells embedded in the circuitry. Once again, however, unless the chip is designed for mass production, design costs can be prohibitive.

Thus since current techniques for repairing defective cells in RAM function blocks typically require additional pro-

cessing to correct these defects, there is a need for enhanced means for correcting such defects.

SUMMARY OF THE INVENTION

In one representative embodiment, an electronic circuit for self-repair of a random access memory array is disclosed wherein the random access array has a plurality of memory storage cells, wherein the storage cells are organized into a plurality of slice arrays. The electronic circuit includes a remap register associated with each slice array, a remap selector circuit associated with each slice array, a write selector circuit associated with each slice array, and a read selector circuit associated with each slice array. When a defect is present in one of the memory storage cells of bit-slice, the remap register informs the remap selector circuit of the defect. When, the remap selector circuit is informed that the defect is present, the remap selector circuit instructs the write selector circuit to redirect data intended for storage in the slice array to an adjacent slice array, otherwise, the remap selector circuit instructs the write selector circuit to direct data intended for storage in the slice array to that slice array. When, the remap selector circuit is informed that the defect is present, the remap selector circuit instructs the read selector circuit to redirect data read from the adjacent slice array to the output of slice array, otherwise, the remap selector circuit instructs the read selector circuit to direct data read from the slice array to that slice array.

Other aspects and advantages of the present invention will become apparent from the following detailed description, taken in conjunction with the accompanying drawings, illustrating by way of example the principles of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings provide visual representations which will be used to more fully describe the invention and can be used by those skilled in the art to better understand it and its inherent advantages. In these drawings, like reference numerals identify corresponding elements and:

FIG. 1 is a diagram of the architecture of a RAM circuit as described in various representative embodiments consistent with the teachings of the invention.

FIG. 2 is a block diagram of an electronic test circuit as described in various representative embodiments consistent with the teachings of the invention.

FIG. 3 is another block diagram of the electronic test circuit as described in various representative embodiments consistent with the teachings of the invention.

FIG. 4 is a block diagram of circuitry for RAM self-repair as described in various representative embodiments consistent with the teachings of the invention.

FIG. 5 is another block diagram of circuitry for RAM self-repair as described in various representative embodiments consistent with the teachings of the invention.

FIG. 6 is yet another block diagram of circuitry for RAM self-repair as described in various representative embodiments consistent with the teachings of the invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

As shown in the drawings for purposes of illustration, the present patent document relates to novel apparatus for the automatic testing of RAM circuits on-chip. Previous cir-

cuitry for on-chip testing have required substantial area on the integrated circuit (IC) chip and have been somewhat removed from the tested area introducing propagation delay errors. By locating the circuitry necessary to perform such test in the addressing and input/output blocks of the RAM, these problems have been reduced.

Also, as shown in the drawings for purposes of illustration, the present patent document relates to novel apparatus for the repair of defective RAM circuits. Previous methods for repair of RAM circuits have typically used techniques such as laser repair which permit the removal of defective parts of the integrated circuit chip and then replacement with a redundant part. However, this process is expensive as an additional processing step is involved. By including the circuitry necessary to repair defects in RAM circuits in the input/output blocks of the RAM, this problem has been negated.

In the following detailed description and in the several figures of the drawings, like elements are identified with like reference numerals.

1. RAM Architecture:

FIG. 1 is a diagram of the architecture of a RAM circuit 105 as described in various representative embodiments consistent with the teachings of the invention. In FIG. 1, memory storage cells 110, also referred to herein as storage cells 110 and more concisely as cells 110, are indicated by small squares. For ease of illustration, only one storage cell 110 is labeled in FIG. 1.

A representative example RAM memory, which is not that shown in FIG. 1, could comprise logically 416 words with 50 bits of data in each word. Using bit-slice architecture for such an example, a slice of cells is created in which each slice represents one bit of data but it is 416 words. During the design phase, a slice is created that is 416 bits high by one bit wide. This slice is then duplicated 50 times to create the complete array. This methodology creates a very tall and fairly narrow array for this example.

By designing the RAM array wherein bits occupying an identical ordinal positional in nearby words are moved to adjacent horizontal positions, a better aspect ratio for the array can be obtained. In the example of FIG. 1, each bit-slice 115 contains eight cells 110 in width instead of one. The array now is only 52 words tall with each word still 50 bits wide. Words now, however, are interleaved on the same row. The aspect ratio of the storage array has become more square in the process resulting in a more compact design. A more compact design is preferable as designs that have long traces running vertically between cells could prevent the RAM from functioning properly at the speeds needed.

The RAM circuit 105 of FIG. 1 includes a RAM array 250, also referred to herein as a random access memory array 250, for storing data. The RAM array 250 is divided into sections referred to herein as slice arrays 118 wherein each slice array 118 includes an associated group of memory storage cells 110.

Also shown in FIG. 1, each bit-slice 115 includes an I/O circuit 130, as well as the associated slice array 118. A control and address block 205 comprises a control circuit 210 and an address selection circuit 120. The control circuit 210 controls test initiation and progress. The address selection circuit 120 enables the selection of memory storage cells 110 for reading and writing of data. In addition, FIG. 1 shows error detection circuit 230 which has inputs from the I/O circuits 130 and outputs information regarding any errors found during the test to the control circuit 210.

2. Overview of Self Test Circuitry:

FIG. 2 is a block diagram of an electronic test circuit 200 as described in various representative embodiments consis-

tent with the teachings of the invention. The electronic test circuit 200 is also referred to herein as electronic circuit 200. The electronic test circuit 200 can be built into the address and I/O circuitry of the RAM circuit 105 and can be programmed to test every cell 110 of the RAM array 250 at wafer test, package test, power-up, as well as other times. The electronic test circuit 200 includes the control circuit 210 which controls the flow of the built-in test and the address selection circuit 120 described above. Data is written into and read out of the bit-slices 115 through the I/O circuit 130 of each bit-slice 115. The results of comparing the data written into the bit-slice 115 and that read out of it is reported to the error detection circuit 230 which reports those results back to the control circuit 210.

FIG. 3 is another block diagram of the electronic test circuit 200 as described in various representative embodiments consistent with the teachings of the invention. In FIG. 3, the various components of the test circuit 200 have been interconnected with other circuits normally present in RAM circuits 105.

3. Detail of Self Test Circuitry—Control Circuit:

The control circuit 210 controls the execution of the test that is performed on the RAM array 250. As shown in FIG. 3, the control circuit 210, has first, second, and third control-circuit inputs 336, 337, 338 and first, second, third, fourth, and fifth control-circuit outputs 341, 342, 343, 344, 345. While shown as a single line, some of these interconnection may, in fact, be multiple wires.

There are a variety of industry standard tests some of which are referred to as March tests that can be employed to test the RAM array 250. The March Tests writes preselected patterns in a preselected order into the RAM array 250 and then reads them back out to verify the integrity of the memory storage cells 110. Different March tests perform their tests in a variety of ways such as whether the test sweeps up or down thru the address space of the RAM array 250 and the number of times that the test is repeated. The test or tests performed, however, could be other than a March test. Regardless of the test performed, it is the control circuit 210 that controls the test.

As the control circuit 210 interacts with the other elements performing the test, various functions and aspects of the control circuit 210 will be discussed in connection with those other elements.

4. Detail of Self Test Circuitry—Test Address Selection Circuit:

The address selection circuit 120 comprises a sequencer 355, an address multiplexer 365, a RAM address register 305, and a comparator 375.

The control circuit 210 sends a first command 350 to the sequencer 355 at a sequencer control input 356 of the sequencer 355. The sequencer 355 also has sequencer data input 357 and a sequencer output 358. The sequencer 355 increments or decrements a memory address 360, wherein the memory address 360 is the memory address of the cell 110 selected for test and stored in the RAM address register 305. The result of the incrementation/decrementation, i.e., the output value of the sequencer 355, is referred to as an indexed memory address 361. Incrementation and decrementation can occur in random or in a preselected pattern, the simplest being to increment or decrement by a single address space. The sequencer control input 356 receives various commands from the first control-circuit output 341 of the control circuit 210. One of these commands is a command to increment. When the increment command is received, the sequencer 355 increments the memory address 360. Another of these commands is a command to decre-

ment. When the decrement command is received, the sequencer 355 decrements the memory address 360.

The second control-circuit output 342 transmits a second command 363 which is received by the address multiplexer 365 on an address-multiplexer control input 366. The address multiplexer 365 also has first, second and third address-multiplexer data inputs 367, 368, 369 and an address-multiplexer output 370. The first address-multiplexer data input 367 receives the incremented/decremented memory address 360 from the sequencer output 358. The second address-multiplexer data input 368 receives an initial self-test memory address 372, wherein the initial self-test memory address 372 is the memory address 360 of the first cell 110 selected for test. The third address-multiplexer data input 369 receives RAM memory storage cell 110 addresses during normal operation of the RAM circuit 105.

When the second command 363 instructs the address multiplexer 365 to select the first address-multiplexer data input 367 as its active input, the address multiplexer 365 transfers contents of the first address-multiplexer data input 367 to the address-multiplexer output 370. When the second command 363 instructs the address multiplexer 365 to select the second address-multiplexer data input 368 as its active input, the address multiplexer 365 transfers contents of the second address-multiplexer data input 368 to the address-multiplexer output 370. And, when the second command 363 instructs the address multiplexer 365 to select the third address-multiplexer data input 369 as its active input, the address multiplexer 365 transfers contents of the third address-multiplexer data input 369 to the address-multiplexer output 370. The address-multiplexer output 370 transfers its contents to the RAM address register 305.

The comparator 375 receives the contents of the RAM address register 305 on a first comparator input 376. The comparator 375 also has a first comparator output 377 and a second comparator output 378. The comparator 375 compares the contents of the RAM address register 305 to the initial self-test memory address 372 and to a final self-test memory address 379. Final self-test memory address 379 is not shown on any of the drawings. For comparison purposes, both the initial self-test memory address 372 and the final self-test memory address 379 could be, for example, hard wired into the comparator 375, obtained from the control circuit 210, or obtained by other means. When the contents of the RAM address register 305 is the same as the initial self-test memory address 372, the first comparator output 377 is set to indicate that the contents of the RAM address register 305 is the same as the initial self-test memory address 372, i.e., at the beginning of the test. When the contents of the RAM address register 305 is the same as the final self-test memory address 379, the second comparator output 378 is set to indicate that the contents of the RAM address register 305 is the same as the final self-test memory address 379, i.e., the end of test has been reached.

The first control-circuit input 336 receives the contents of the first comparator output 377. When the first comparator output 377 indicates that the contents of the RAM address register 305 is the same as the initial self-test memory address 372, the control circuit 210 is so informed at first control-circuit input 336. When the second comparator output 378 indicates that the contents of the RAM address register 305 is the same as the final self-test memory address 379, the control circuit 210 is so informed at second control-circuit input 337. The control circuit 210 may sweep through various test sequences and may repeat those test sequences in various orders before it terminates the test.

An important characteristic of the control circuit 210 is that it is independent of the size of the RAM. It has no

knowledge or dependence on the size of RAM addressing. It uses the initial self-test memory address 372 comparison result as reported at the first comparator output 377 and the final self-test memory address 379 comparison result as reported at the second comparator output 378 to tell it where to start and where to stop testing. As a result, once designed the control circuit 210 can be used again and again for different RAM blocks on different integrated circuit chips.

5. Detail of Self Test Circuitry—I/O Circuit:

Again in FIG. 3, various components of the test circuit 200 have been interconnected with other circuits normally present in RAM circuits 105. During normal operation, operational data 380 is inputted into input register 381 and is written into the slice array 118. Data is retrieved from the slice array 118 and written into output register 383.

The I/O circuit 130 comprises components common to the bit-slice 115, the input register 381 and the output register 383, as well as a data-in multiplexer 1305, an inverter 1315, an input-complement multiplexer 1320, an output-complement multiplexer 1330, and an exclusive-OR gate 1340. All components are present in the I/O circuit 130 regardless of whether tests are being performed or normal data operations are progressing. The data is merely routed according to the operating mode. An input path from the input-complement multiplexer 1320 to the slice array 118 and an output path from the slice array 118 to the output register 383 are shown in FIG. 3. However, in other embodiments both paths could time share the same transmission path.

The data-in multiplexer 1305 has first and second data-in-multiplexer data inputs 1306, 1307, a data-in-multiplexer control input 1308, and a data-in-multiplexer output 1309. The first data-in-multiplexer data input 1306 receives a test data 1310, and the second data-in-multiplexer data input 1307 receives operational data 380.

When the control circuit 210 instructs the data-in multiplexer 1305 that it is executing the test, the third control-circuit output 343 transmits a command to the data-in-multiplexer control input 1308 to select the first data-in-multiplexer data input 1306 as the active input and to transfer contents of the first data-in-multiplexer data input 1306 to the data-in-multiplexer output 1309. Otherwise, the third control-circuit output 343 transmits a command to the data-in-multiplexer control input 1308 to select the second data-in-multiplexer data input 1307 as the active input and to transfer contents of the second data-in-multiplexer data input 1307, i.e., normal operational data 380, to the data-in-multiplexer output 1309. The data-in-multiplexer control input 1308 is preferably two bits wide to accommodate the required commands.

The input register 381 receives data from the data-in-multiplexer output 1309, and the inverter 1315 receives data from the input register 381.

The input-complement multiplexer 1320 has first and second input-complement-multiplexer data inputs 1321, 1322, an input-complement-multiplexer control input 1323, and an input-complement-multiplexer output 1324. The first input-complement-multiplexer data input 1321 receives data from the input register 381, and the second input-complement-multiplexer data input 1322 receives the output of the inverter 1315.

The output-complement multiplexer 1330 has first and second output-complement-multiplexer data inputs 1331, 1332, an output-complement-multiplexer control input 1333, and an output-complement-multiplexer output 1334. The first output-complement-multiplexer data input 1331 receives data from the input register 381, and the second

output-complement-multiplexer data input **1332** receives the output of the inverter **1315**.

When the control circuit **210** instructs the input-complement multiplexer **1320** that it is to write the test data **1310**, the fourth control-circuit output **344** transmits a command to the input-complement-multiplexer control input **1323** to select the first input-complement-multiplexer data input **1321** as the active input and to transfer contents of the first input-complement-multiplexer data input **1321** to the input-complement-multiplexer output **1324**. When the control circuit **210** instructs the input-complement multiplexer **1320** that it is to write the inverse test data, the fourth control-circuit output **344** transmits a command to the input-complement-multiplexer control input **1323** to select the second input-complement-multiplexer data input **1322** as the active input and to transfer contents of the second input-complement-multiplexer data input **1322** to the input-complement-multiplexer output **1324**.

During normal operation, i.e., not test, the input-complement multiplexer **1320** transfers operational data **380** stored in the input register **381** from first input-complement-multiplexer data input **1321** to the input-complement-multiplexer output **1324**.

The output-complement multiplexer **1330** and the exclusive-OR gate **1340** are used to compare the data read from the slice array **118** with the expected value as stored in the input register **381**.

The output-complement multiplexer **1330** has first and second output-complement-multiplexer data inputs **1331**, **1332**, the output-complement-multiplexer control input **1333**, and the output-complement-multiplexer output **1334**. The first output-complement-multiplexer data input **1331** receives data from the input register **381**, and the second output-complement-multiplexer data input **1332** receives the output of the inverter **1315**.

When the control circuit **210** instructs the output-complement multiplexer **1330** that it is to select the test data for comparison which is stored in the input register **381**, the fifth control-circuit output **345** transmits command to the output-complement-multiplexer control input **1333** to select the first output-complement-multiplexer data input **1331** as the active input and to transfer contents of the input register **381** to the output-complement-multiplexer output **1334**, otherwise the fifth control-circuit output **345** transmits command to the output-complement-multiplexer control input **1333** to select the second output-complement-multiplexer data input **1332** as the active input and to transfer contents of the inverter output **1315** to the output-complement-multiplexer output **1334**. During normal operation, it is irrelevant whether first output-complement-multiplexer data input **1331** or second output-complement-multiplexer data input **1332** is transferred to the output-complement-multiplexer output **1334**. However, in the representative embodiment, the first output-complement-multiplexer data input **1331** is transferred to the output-complement-multiplexer output **1334**.

The exclusive-OR gate **1340** has first and second exclusive-OR-gate inputs **1341**, **1342** and an exclusive-OR-gate output **1343**. The first exclusive-OR-gate input **1341** receives data from the output register **383**, and the second exclusive-OR-gate input **1342** receives the output-complement-multiplexer output **1334**.

The exclusive-OR gate **1340** is used to compare the data read from the slice array **118**, which is stored in the output register **383** and presented to the first exclusive-OR-gate input **1341** with the expected value which is stored in the input register **381** and presented to the second exclusive-

OR-gate input **1342**. When the data in the output register **383** matches that of the expected data the exclusive-OR gate **1340** outputs a binary zero to the exclusive-OR-gate output **1343** indicating a success. Otherwise, the exclusive-OR gate **1340** outputs a binary one to the exclusive-OR-gate output **1343** indicating a failure.

6. Detail of Self Test Circuitry—Error Detection Circuit:

The error detection circuit **230** has a plurality of error detection circuit inputs **231** and a single error detection circuit output **232**. The output of each exclusive-OR-gate output **1343** is transferred to its associated error detection circuit input **231**. The error detection circuit **230** combines the results of the exclusive-OR gates **1340** for every bit-slice **115** and reports the result to the control circuit **210** via the error detection circuit output **232** to the third control-circuit input **338**.

7. Redundant RAM Model:

FIG. 4 is a block diagram of circuitry for RAM self-repair as described in various representative embodiments consistent with the teachings of the invention. In FIG. 4, the RAM array **250** is divided into bit-slices **115**, each of which includes its associated slice array **118** and I/O circuit **130** as previously stated. The RAM array **250** also comprises a redundant slice **410**. Should the RAM array **250** not have any defects, the redundant slice **410** is not used. However, should a defect be encountered, data flow is routed around the bit-slice **115** containing the defect, and the redundant slice **410** is used in its place. The following error types, which are the five most common defect mechanisms, can be corrected using the techniques disclosed herein: (1) single bit, (2) paired bit (two adjacent bits within the same slice), (3) single column, and (4) paired column (two adjacent columns within the same slice), and (5) slice. Essentially any and all defects occurring in the same slice can be repaired as repair occurs via a remapping of slices.

In the example of FIG. 4, the bit-slice **115** corresponding to k-th bit-slice **115** contains a defect **415** which is corrected by rerouting bit-slice I/O for all bit-slices **115** to the right of and including the bit-slice **115** for the k-th bit-slice **115**. Each bit-slice comprises two I/O paths, a normal bit-slice I/O path **420** and an alternate bit-slice I/O path **425**. Bit-slices **115** to the left of the bit-slice **115** containing the defect **415** utilize their normal bit-slice I/O paths **420** for input/output of those bit-slices **115**. The bit-slice **115** containing the defect **415** and all bit-slices **115** to the right of that bit-slice **115** utilize their alternate bit-slice I/O paths **425** for input/output of those bit-slices **115**. Thus, all bit-slices **115** to the right of the bit-slice **115** containing the defect **415**, as well as the redundant slice **410**, are mapped to the I/O circuit **130** to their immediate left.

8. Overview of Redundant RAM Circuitry:

FIG. 5 is another block diagram of circuitry for RAM self-repair as described in various representative embodiments consistent with the teachings of the invention. As in FIG. 4, it is assumed that a defect occurs in the k-th slice array **118**. In such case, a remap register **515** for the k-th bit-slice **115** informs remap selector circuit **520** to redirect data for the k-th bit-slice **115** to the (k-1)-th bit-slice **115** for storage in the (k-1)-th slice array **118**. The remap selector circuit **520** in turn instructs a write selector circuit **505** for the k-th bit-slice **115** to write the data for the k-th bit-slice **115** into the (k-1)-th slice array **118**.

The remap register **515** for the k-th bit-slice **115** informs remap selector circuit **520** to redirect data read from the (k-1)-th slice array **118** to the k-th bit-slice **115** for transfer out. The remap selector circuit **520** in turn instructs a read selector circuit **510** for the k-th bit-slice **115** to read the data for the k-th bit-slice **115** from the (k-1)-th slice array **118**.

FIG. 6 is yet another block diagram of circuitry for RAM self-repair as described in various representative embodiments consistent with the teachings of the invention. FIG. 6 shows various circuitry from previous figures. In particular this circuitry includes (1) the input register **381**, (2) the input-complement multiplexer **1320**, (3) the output-complement multiplexer **1330**, (4) the slice array **118**, (5) the output register **383**, and (6) the exclusive-OR gate **1340**.

In addition to the circuitry used for normal RAM read/write functions and defect detection, circuitry necessary for defect repair is as follows: (1) a write multiplexer **605**, (2) a read multiplexer **610**, (3) the remap register **515**, and (4) an OR gate **620**. The write multiplexer **605** has first and second write-multiplexer inputs **606,607**, a write-multiplexer control input **608**, and a write-multiplexer output **609**. The read multiplexer **610** has first and second read-multiplexer inputs **611,612**, a read-multiplexer control input **613**, and a read-multiplexer output **614**. The remap register **515** has a remap-register input **616** and a remap-register output **617**. The OR gate **620** has first and second OR-gate inputs **621,622** and an OR-gate output **623**.

As long as no defects **415** occur to the left of or in bit-slice "k" **115** in FIG. 6, the write multiplexer **605** is enabled so as to write operational data **380** from the input register **381** into its associated bit-slice **115** through input-complement multiplexer **1320**. The function of input-complement multiplexer **1320** was explained in the discussion of FIG. 3. Also, the read multiplexer **610** is enabled so as to read data stored in the associate RAM bit-slice **115** into the output register **383** associated with that RAM bit-slice **115**. When the output of the OR gate **620**, identified as OR-gate output **623**, is a binary zero, both inputs to the OR gate **620**, identified as first OR-gate input **621** and second OR-gate input **622**, are binary zero. The binary zero at the first OR-gate input **621** indicates that no defects were found in any of the bit-slices **115** to the left of the k-th bit-slice **115**, and the binary zero at the second OR-gate input **622** indicates that the k-th bit-slice **115** is free of defects **415**. The fact that no defects **415** were found in the k-th bit-slice **115** during the test phase is recorded in the remap register **515** by storing a binary zero in it.

If, however, a defect **415** occurs in the k-th bit-slice **115** that fact is recorded in remap register **515**. The fact that defect **415** is present in the k-th bit-slice **115** would have been detected during the test phase. In a representative application, the remap register **515** then would have a binary one value stored in it. The OR-gate output **623** then becomes a binary one which switches the k-th write multiplexer **605** to write the value from the (k+1)-th input register **381** into the memory of the k-th bit-slice **115**. This action is, however, of no consequence as any data in the k-th bit-slice **115** will be ignored since it is known to have the defect **415**. Of more importance is the fact that the read multiplexer control input switches the read multiplexer **610** for the k-th bit-slice **115** to read data from the (k-1)-th bit-slice **115** into the output register **383** for the k-th bit-slice **115** instead of the (k-1)-th bit-slice **115**.

Since the OR-gate output **623** for the k-th bit-slice **115** provides the first OR-gate input **621**, the OR-gate output **623** for the (k-1)-th bit-slice **115** becomes a binary one indicating that the defect **415** occurred in a bit-slice **115** prior to that of the (k-1)-th bit-slice **115**. This value for the output of the OR gate **620** for the (k-1)-th bit-slice **115** switches the write multiplexer **605** for the (k-1)-th bit-slice **115** to write the operational data **380** from the input register **381** of the k-th bit-slice **115** to be written into the memory of the (k-1)-th bit-slice **115**.

In a manner similar to that described above, the data stored in the (k-2)-th bit-slice **115** will be read out by the read multiplexer **610** of the (k-1)-th bit-slice **115** into the output register **383** of the (k-1)-th bit-slice **115**. Thus, all remapping of data for both read and write functions is programmed into the remap registers **515** when the RAM array **250** is tested.

9. Concluding Remarks:

In representative embodiments of the apparatus described in the present patent document, techniques for the on-chip testing of RAM circuits on-chip are disclosed. Present techniques for on-chip testing do not require substantial area on the chip and are inherently located closer to the tested area which reduces propagation delay errors. By locating the circuitry necessary to perform such test in the addressing and input/output blocks of the RAM, these advantages have been obtained.

In other representative embodiments of the apparatus described in the present patent document, techniques for the soft repair of defective RAM circuits are disclosed. Present techniques for repair of RAM circuits do not use techniques such as laser repair in the removal of defective parts of the IC and its replacement with a redundant part. The present process is inexpensive and no additional processing steps are involved. By including the circuitry necessary to repair defects in RAM circuits in the input/output blocks of the RAM, these advantages have been obtained.

While the present invention has been described in detail in relation to representative embodiments thereof, the described embodiments have been presented by way of example and not by way of limitation. It will be understood by those skilled in the art that various changes may be made in the form and details of the described embodiments resulting in equivalent embodiments that remain within the scope of the appended claims.

What is claimed is:

1. An electronic circuit for self-repair of a random access memory array, comprising:

a write selector circuit associated with each slice array, wherein the random access memory is organized into a plurality of slice arrays, wherein each slice array comprises at least one memory storage cell, and wherein at least one of the slice arrays is redundant;

a read selector circuit associated with each slice array;

a remap selector circuit associated with each slice array; and

a remap register associated with each slice array, wherein when power is applied to the circuit, the circuit automatically performs a self-test, wherein when the self-test detects a defect, the remap register of the slice array having the defect is set to indicate the presence of the defect resulting in the associated remap selector circuit instructing the associated write selector circuit to redirect data intended for storage in that slice array to an adjacent slice array and instructing the associated read selector circuit to redirect data read from the adjacent slice array to the output of the defective slice array, wherein the remap selector circuit associated with each slice array comprises an OR-gate, wherein the OR-gate has a first OR-gate input, a second OR-gate input, and an OR-gate output, wherein the first OR-gate input is connected to the OR-gate output associated with the adjacent higher-numbered slice array, wherein the second OR-gate input is connected to the output of the remap register, and wherein the OR-gate output is connected to the input of the write selector circuit and the read selector circuit.

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2. The electronic circuit as recited in claim 1, wherein when the self-test detects that one of the slice arrays is defect free, the remap register associated with that slice array is set to indicate that the slice array is defect free resulting in the associated remap selector circuit instructing the associated write selector circuit to direct data intended for storage in that slice array to that slice array and instructing the associated read selector circuit to direct data read from that slice array to the output of that slice array.

3. The electronic circuit as recited in claim 1, wherein the electronic circuit is embedded within a bit-slice in an integrated circuit, wherein the bit-slice comprises slice array and other circuitry associated with the slice array.

4. The electronic circuit as recited in claim 1, wherein when the defect is present:

for each slice array subsequent to the slice array in which the defect is present, the remap selector circuit instructs the write selector circuit to redirect data intended for storage in that slice array to its adjacent slice array, and

for each slice array subsequent to the slice array in which the defect is present, the remap selector circuit instructs the read selector circuit to redirect data read from its adjacent slice array to the output of the slice array.

5. The electronic circuit as recited in claim 1, wherein the electronic circuit is an integrated circuit.

6. An electronic circuit for self-repair of a random access memory array, comprising:

a write selector circuit associated with each slice array, wherein the random access memory is organized into a plurality of slice arrays, wherein each slice array comprises at least one memory storage cell, and wherein at least one of the slice arrays is redundant;

a read selector circuit associated with each slice array;

a remap selector circuit associated with each slice array, and

a remap register associated with each slice array, wherein when power is applied to the circuit, the circuit automatically performs a self-test, wherein when the self-test detects a defect, the remap register of the slice array having the defect is set to indicate the presence of the defect resulting in the associated remap selector circuit instructing the associated write selector circuit to redirect data intended for storage in that slice array to an adjacent slice array and instructing the associated read selector circuit to redirect data read from the adjacent slice array to the output of the defective slice array, wherein the write selector circuit associated with each slice array comprises a write multiplexer, wherein the write multiplexer has a first write-multiplexer input, a second write-multiplexer input, a write-multiplexer control input, and a write-multiplexer output, wherein the write-multiplexer control input is connected to the output of the remap selector circuit, wherein the first write-multiplexer input is connected to the second write-multiplexer input associated with the adjacent higher-numbered slice array, wherein the second write-multiplexer input is connected to an output of an input register, and wherein the write-multiplexer output is capable of transferring data to the slice array.

7. The electronic circuit as recited in claim 6, wherein when the self-test detects that one of the slice arrays is defect free, the remap register associated with that slice array is set to indicate that the slice array is defect free resulting in the associated remap selector circuit instructing the associated write selector circuit to direct data intended for storage in that slice array to that slice array and instructing the asso-

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ciated read selector circuit to direct data read from that slice array to the output of that slice array.

8. The electronic circuit as recited in claim 6, wherein the electronic circuit is embedded within a bit-slice an integrated circuit, wherein the bit-slice comprises the slice array and other circuitry associated with the slice way.

9. The circuit as recited in claim 6, wherein when the defect is present:

for each slice array subsequent to the slice way in which the defect is present, the remap selector circuit instructs the write selector circuit to redirect data intended for storage in that slice array to its adjacent slice array, and

for each slice array subsequent to the slice array in which the defect is present, the remap selector circuit instructs the read selector circuit to redirect data read from its adjacent slice array to the output of the slice array.

10. The electronic circuit as recited in claim 6, wherein the electronic circuit is an integrated circuit.

11. An electronic circuit for self-repair of a random access memory array, comprising:

a write selector circuit associated with each slice array, wherein the random access memory is organized into a plurality of slice arrays, wherein each slice array comprises at least one memory storage cell, and wherein at least one of the slice arrays is redundant;

a read selector circuit associated with each slice array;

a remap selector circuit associated with each slice array; and

a remap register associated with each slice array, wherein when power is applied to the circuit, the circuit automatically performs a self-test, wherein when the self-test detects a defect, the remap register of the slice array having the defect is set to indicate the presence of the defect resulting in the associated remap selector circuit instructing the associated write selector circuit to redirect data intended for storage in that slice array to an adjacent slice array and instructing the associated read selector circuit to redirect data read from the adjacent slice array to the output of the defective slice array, wherein the read selector circuit associated with each slice array comprises a read multiplexer, wherein the read multiplexer has a first read-multiplexer input, a second read-multiplexer input, a read-multiplexer control input, and a read-multiplexer output, wherein the read-multiplexer control input is connected to the output of the remap selector circuit, wherein the first read-multiplexer input is capable of obtaining data from the slice array, wherein the second read-multiplexer input is connected to the first read-multiplexer input associated with the adjacent lower-numbered slice array, and wherein the read-multiplexer output is capable of transferring data to an output register.

12. The electronic circuit as recited in claim 11, wherein when the self-test detects that one of the slice arrays is defect free, the remap register associated with that slice may is set to indicate that the slice array is defect free resulting in the associated remap selector circuit instructing the associated write selector circuit to direct data intended for storage in that slice array to that slice way and instructing the associated read selector circuit to direct data read from that slice array to the output of that slice array.

13. The electronic circuit as recited in claim 11, wherein the electronic circuit is embedded within a bit-slice in an

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integrated circuit, wherein the bit-slice comprises the slice array and other circuitry associated with the slice array.

14. The electronic circuit recited in claim **11**, wherein when the defect is present:

for each slice array subsequent to the slice array in which the defect is present, the remap selector circuit instructs the write selector circuit to redirect data intended for storage in that slice way to its adjacent slice array, and

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for each slice array subsequent to the slice array in which the defect is present, the remap selector circuit instructs the read selector circuit to redirect data read from its adjacent slice array to the output of the slice array.

15. The electronic circuit as recited in claim **11**, wherein the electronic circuit is an integrated circuit.

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